Advances in transmission electron microscopy

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Advances in transmission electron microscopy: in situ nanoindentation and in situ straining experiments

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Undisputedly microscopy plays a predominant role in unraveling the underpinning mechanisms in plastic deformation of materials. There are at least two reasons that hamper a straightforward correlation between microscopic structural information and mechanical properties: one fundamental and one practical reason. First, the defects affecting these properties, like dislocations, are in fact not in thermodynamic equilibrium and their behavior is very much non-linear. Second, a quantitative evaluation of the structure-property relationship can be rather difficult because of statistics. In particular, situations where there is only a small volume fraction of defects present or a very inhomogeneous distribution statistical sampling may be a problem. A major drawback of experimental research in the field of crystalline defects is that most of the microscopy work has been concentrated on static structures.

Direct observation of dislocation behavior during indentation has recently become possible through in-situ nanoindentation in a transmission electron microscope. In this contribution we will concentrate on the dynamic effects of dislocations and cracks in crystalline and amorphous metals observed with in-situ TEM nanoindentations and in-situ TEM straining experiments. The objective of this contribution is not to address all the various deformation mechanisms in metallic systems but rather to discuss the various recent advances in in-situ TEM techniques that can be helpful in attaining a more quantitative understanding of the dynamics of dislocations, see Figure 1 [1,2].

Besides moving dislocations in crystalline materials, significant progress has been made in recent years in the understanding of the associated deformation and crack propagation in amorphous metals, together with possible control of shear band propagation by virtue of (nano-)crystalline additions in order to suppress the tendency for instantaneous catastrophic failure. However, it is also apparent that there is still much inconsistency, and whilst many sound hypotheses and proofs abound, clarity is often lacking when comparing published results. The shear band thickness lies in the range to be 10 – 20 nm for several BMG compositions. TEM should be a suitable tool for this kind of analysis of shear band formation in metallic glasses, since their thicknesses are very low and it may be expected that shear bands may lead to (nano-scale) structural changes in amorphous materials, see Figure 2 [3].

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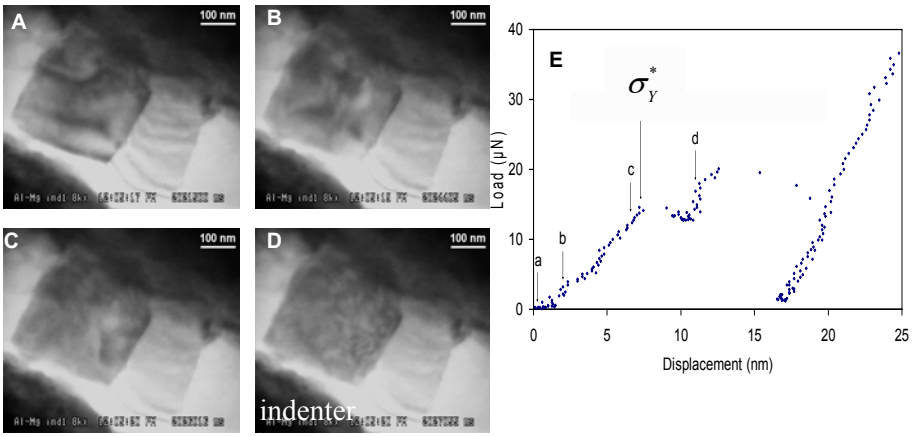

Figure 1. TEM bright- field Image sequence (a-d) from the initial loading portion (e) of the indentation on Al-2.6%Mg. The first dislocations are nucleated between (a) and (b), i.e. prior to the apparent yield point. The nucleation is evidenced by an abrupt change in image contrast: before nucleation, only thickness fringes can be seen, whereas more complex contrast features become visible at the instant of nucleation.
see http://www.dehosson.fmns.rug.nl/.

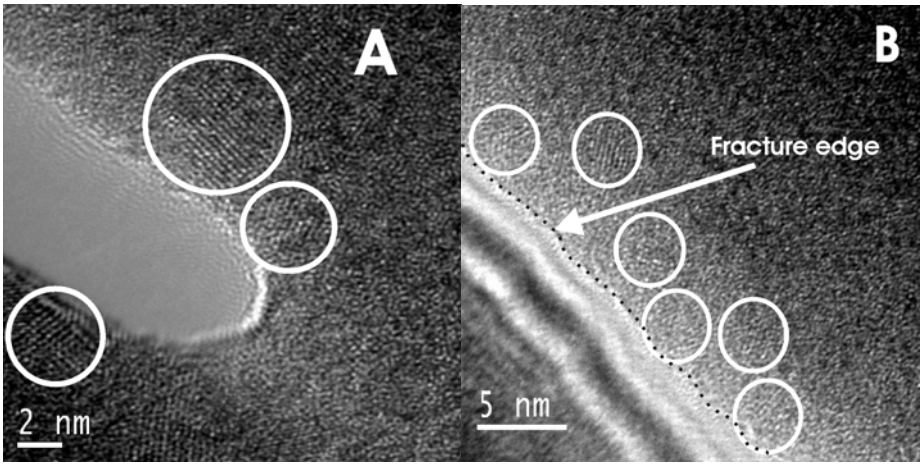

Figure 2. HRTEM micrographs revealing (a) a rapid-propagation induced meniscus at the crack-tip for $Cu_{47}Ti_{33}Zr_{11}Ni_6Sn_2Si_1$ ribbon (b) HRTEM image revealing nano-crystallization close to the fracture surface edge for $Zr_{50}Cu_{30}Ni_{10}Al_{10}$